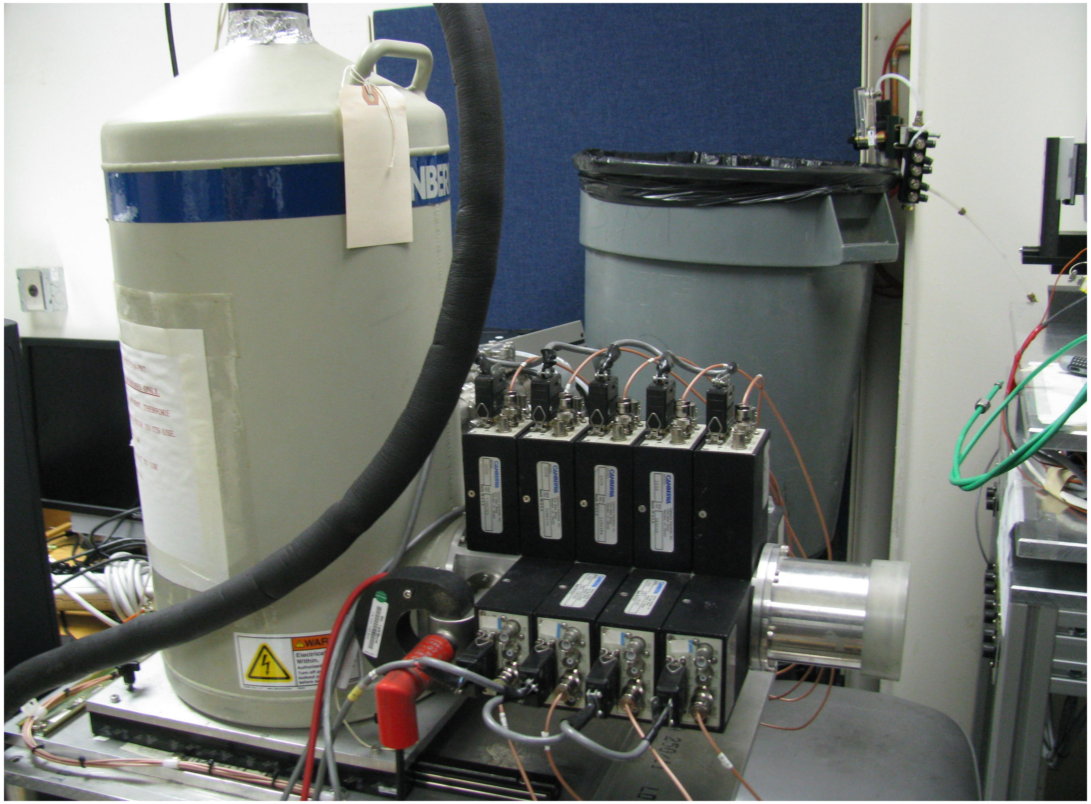
# Photon Science applications

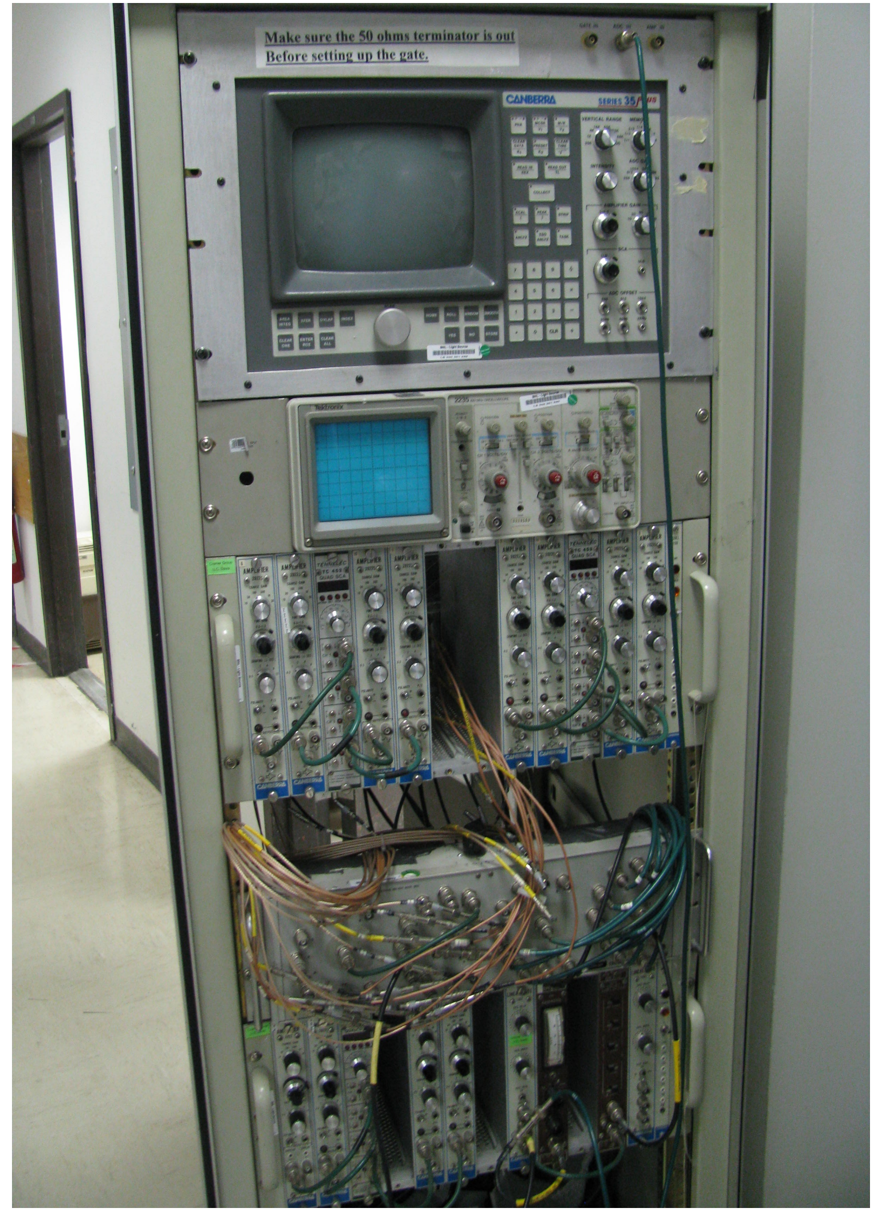
D. Peter Siddons

# ....It's a long story!

- As an example of my association with Veljko in particular and Instrumentation Division in general I'll tell the story of multi-element detectors for x-ray spectroscopy at BNL.
- It all started with Steve Cramer (ex-NSLS, now UC Davies) and Hobie Kraner in ~1990
  - LDRD: “A 100-element detector for high-rate EXAFS measurements”
- EXAFS: Extended X-ray Absorption Fine Structure, a very popular structural technique for non-crystalline materials

# Prior art






- Canberra 13-element HPGe detector
- NIM / CAMAC data acquisition
- This was the first such detector ever made, developed by Steve Cramer and Canberra in 1988.

# Pre-ASIC days

Nuclear Instruments and Methods in Physics Research A319 (1992) 408–413
North-Holland

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

## The NSLS 100 element solid state array detector

L.R. Furenlid [a], H.W. Kraner [b], L.C. Rogers [b], S.P. Cramer [c], D. Stephani [b], R.H. Beuttenmuller [b] and J. Beren [a]

[a] *National Synchrotron Light Source, Brookhaven National Laboratory, Upton, NY 11973, USA*
[b] *Instrumentation Division, Brookhaven National Laboratory, Upton, NY 11973, USA*
[c] *Department of Applied Science, University of California at Davis, Davis, CA 95616, USA*

### 8. Conclusion

The full sensitivity of fluorescence X-ray absorption spectroscopy is only achieved when:
1) the detector has sufficient resolution to separate the desired trace element fluorescence from background signals,
2) the detector is fast enough to respond to all available photons, and
3) the detector subtends a large solid angle with small dead area.

The NSLS 100 element solid state detector is designed to meet these criteria and help advance the state of the art in X-ray detector technology. It will significantly

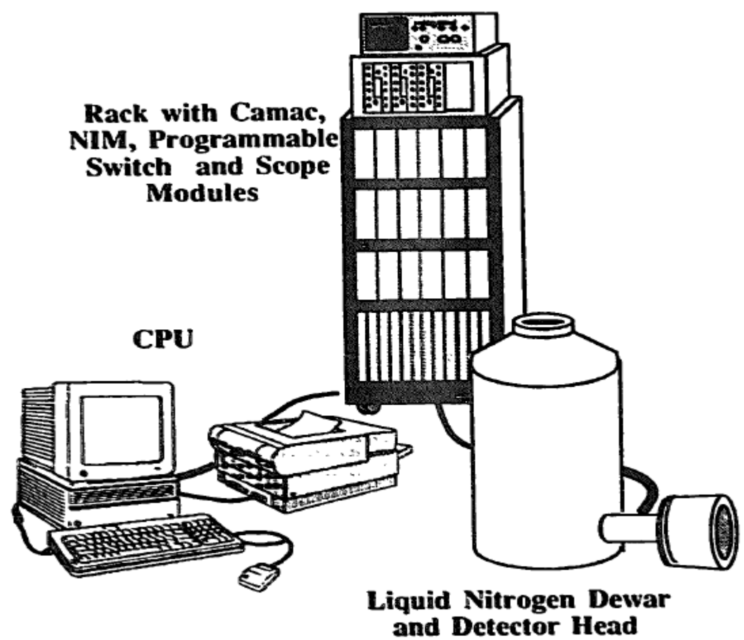



Fig. 2. Components of the 100 element detector.

- Note: 3 authors from NSLS, 4 from Inst. Div.
  - This version was never actually completed
  - because.......

# Proposed detector head

- The preamp was to have resistive feedback (a la Stephani hybrid)
- For such small signals, the feedback resistor needed to be in the $G\Omega$ range.
- No suitable miniature large-value resistor was available.

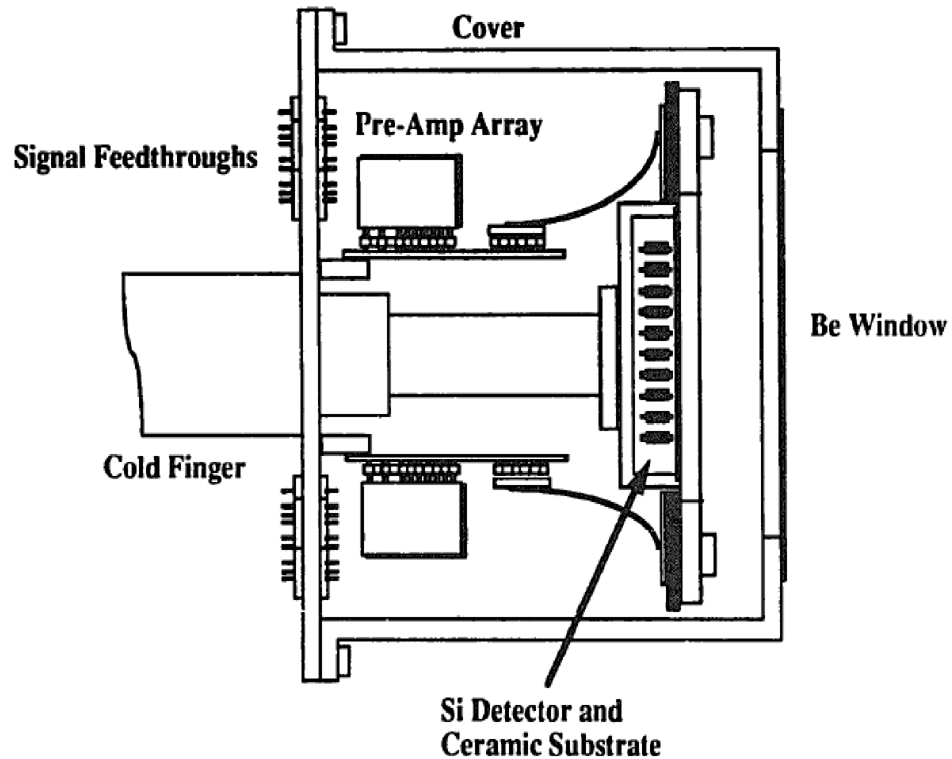



Fig. 3. Detector head cross-section drawing.

# Solution: the resistorless preamp (1994)

**SILICON DETECTOR SYSTEM FOR HIGH RATE EXAFS APPLICATIONS**

A. Pullia+, H. W. Kraner++, D. P. Siddons++, L. R. Furenlid++, G. Bertuccio+

+Politecnico di Milano, Dipartimento di Elettronica e Informazione, P.za Leonardo da Vinci 32, 20133 Milano Italy.
++Brookhaven National Laboratory, Upton, NY 11973-5000, USA.

- Alberto Pullia visited from Bertuccio's lab and implemented this as a solution to the resistor problem. He also designed a variable-$\tau$ shaper. Both were implemented as surface-mount PCBs for high-density packaging.
- This formed the basis of the fully-implemented 100-element detector (actually 120-elements).

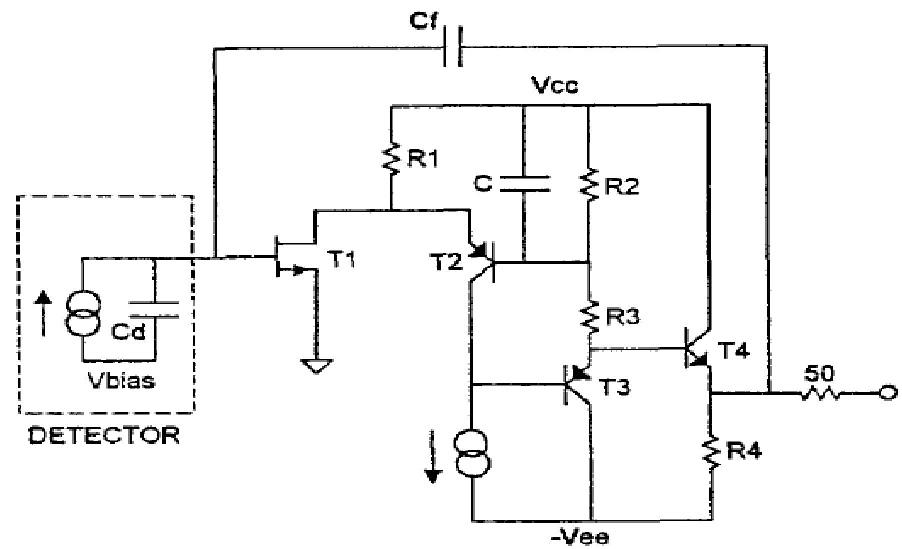
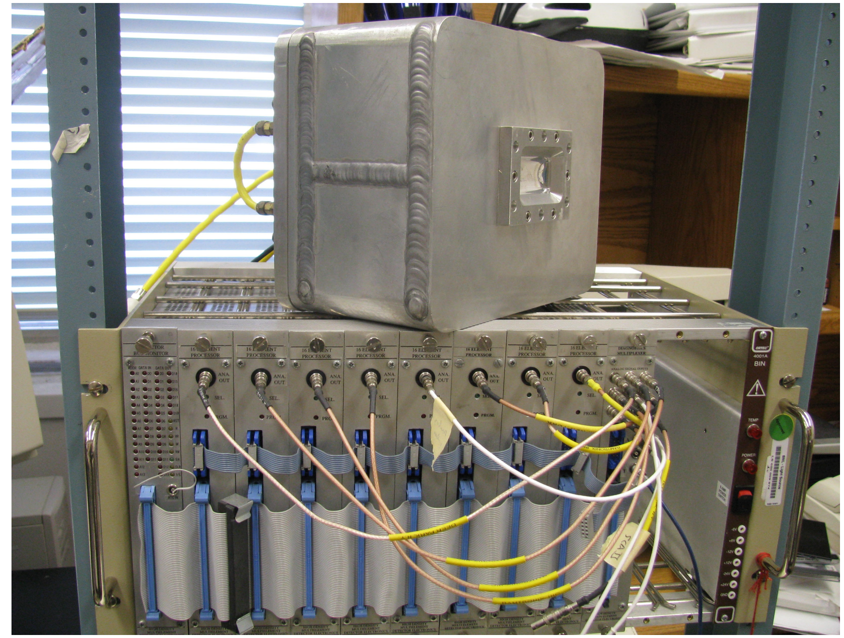


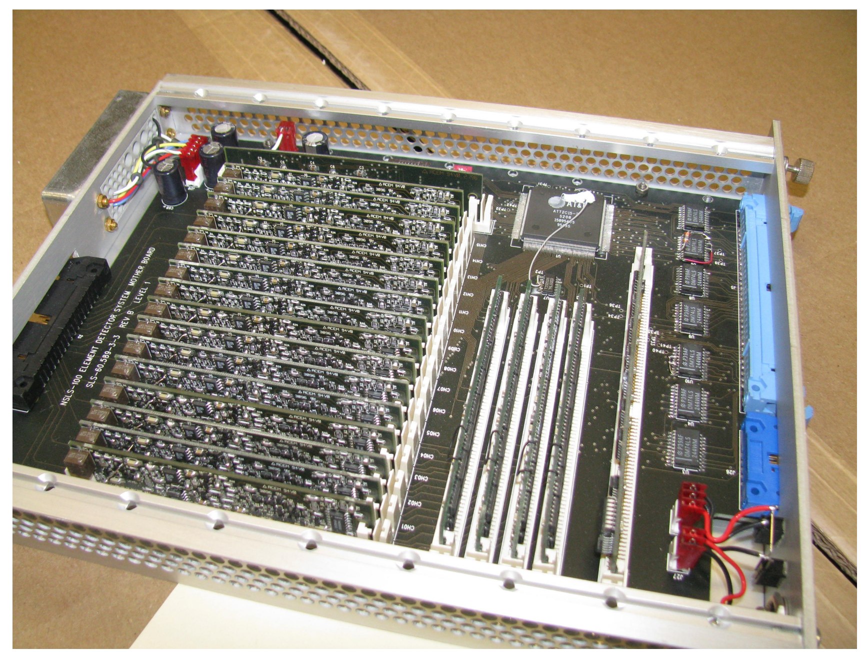

Fig. 2. Forward Bias Feedback Charge Preamplifier

[2] G. Bertuccio, P. Rehak, and D. Xi, "A novel charge sensitive preamplifier without the feedback resistor", Nucl. Instrum. and Methods A326 (1993) pp. 71-76.

# Pictures of 100-element

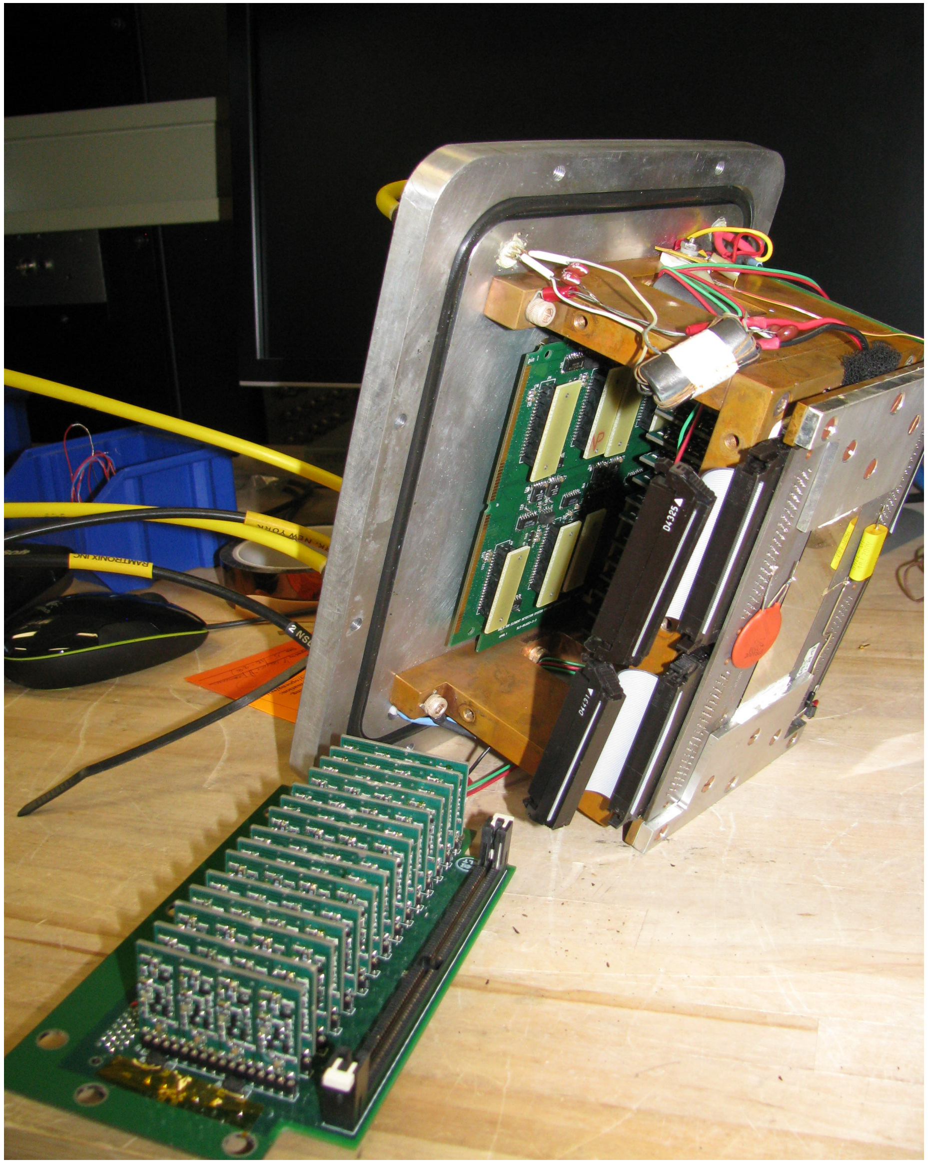
- Based on surface-mount technology
- 8 modules, 16 channels/module
- Shapers, discriminators and level-setting DACs
- Custom parallel bus to Labview / Mac.
- Coax ribbon umbilical taking preamp signals to modules.
- 48 32-bit scalers implemented in an FPGA (first FPGA-based project in NSLS, done by Phil Pietraski, ex-NSLS, now ?)
- Friendly graphical user interface, written by Lars.





# Detector head

- 120 sensors, each 1.5mm x 1.5mm
- 32 quad preamp surface-mount modules
- Peltier coolers with water heat extraction
- Operates at -30C in vacuum.



# ....Enter microelectronics

- Veljko knew that the future lay in IC design for complex detector readout
  - Paul O'Connor hired in 1990
  - Gianluigi De Geronimo hired in 1997
  - First low-noise front-end chip
  - ...and many more after that.

# Self-biasing front-end

ELSEVIER

Nuclear Instruments and Methods in Physics Research A 390 (1997) 241–250

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

CMOS preamplifier for low-capacitance detectors[1]

G. Gramegna[a], P. O'Connor[b,*], P. Rehak[b], S. Hart[c]

[a] Politecnico. di Bari, Italy
[b] Brookhaven National Laboratory, Bldg 535B, P.O. Box 5000, Upton, NY 11973, USA
[c] Wayne State University, USA

Received 5 July 1996; revised form received 30 December 1996

- Basis for many chips
- Very easy to use:
  - no analog controls
  - DC coupled input
  - Wide leakage current tolerance

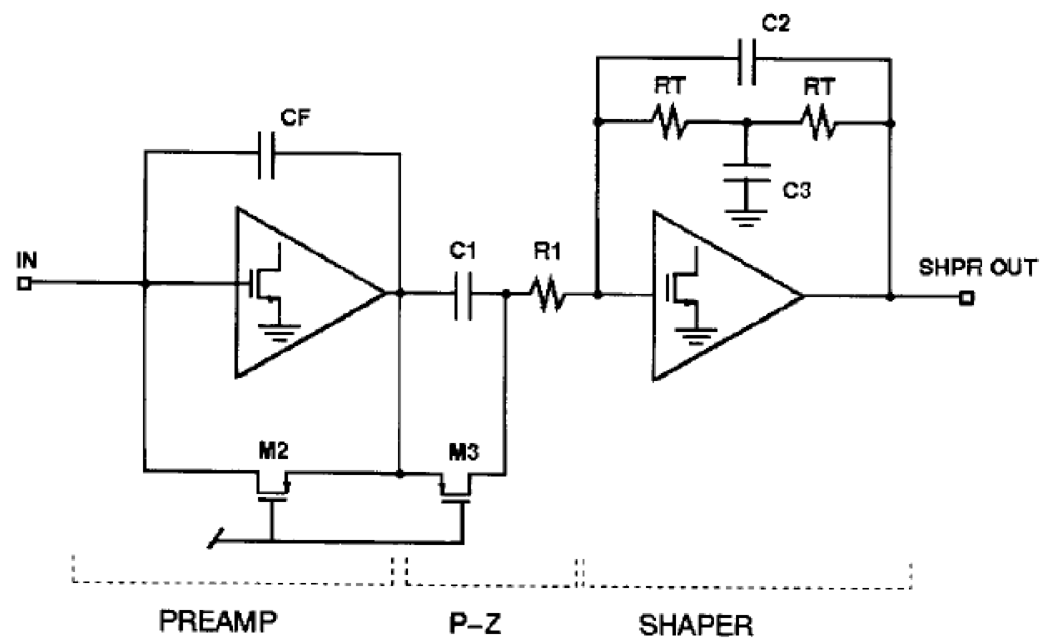
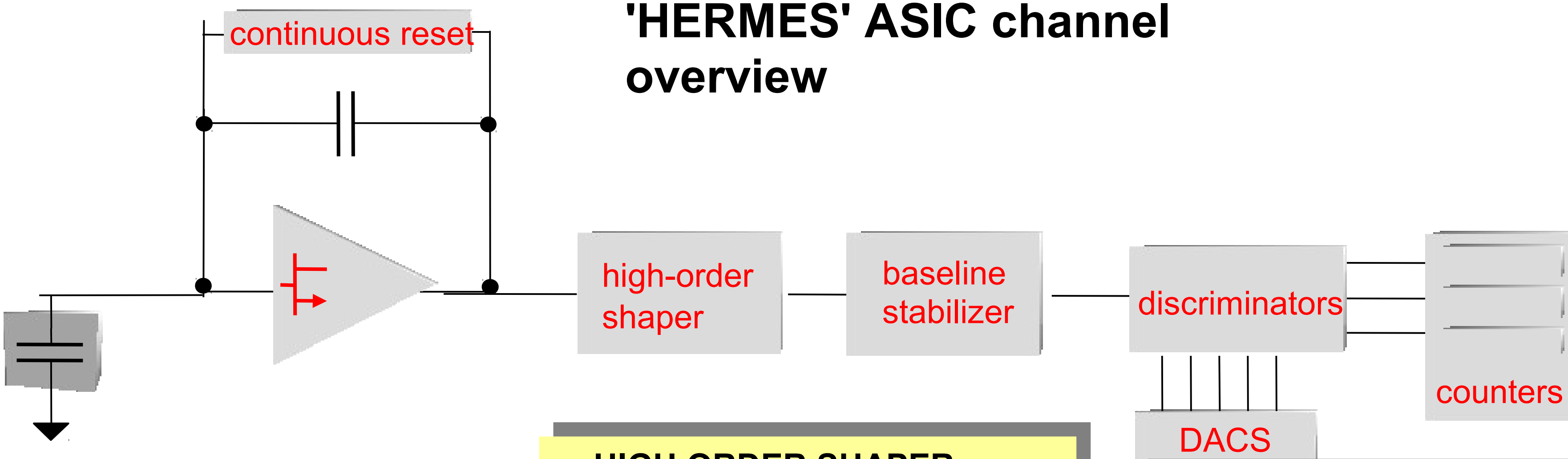



Fig. 3. Shaper and pole-zero cancellation.

# Hermes: a low-noise workhorse ASIC

**'HERMES' ASIC channel overview**




**INPUT p-MOSFET**

- optimized for operating region
- NIM A480, p.713

**CONTINUOUS RESET**

- feedback MOSFET
- self adaptive 1pA - 100pA
- low noise < 3.5e$^-$ rms @ 1μs
- highly linear < 0.2% FS
- US patent 5,793,254
- NIM A421, p.322
- TNS 47, p.1458

≈ 3 mW

**HIGH ORDER SHAPER**

- amplifier with passive feedback
- 5$^{th}$ order complex semigaussian
- 2.6x better resolution vs 2$^{nd}$ order
- TNS 47, p.1857

**BASELINE STABILIZER (BLH)**

- low-frequency feedback, BGR
- slew-rate limited follower
- DC and high-rate stabilization
- dispersion < 3mV rms
- stability <2mV rms @ rt×tp<0.1
- TNS 47, p.818

**DISCRIMINATORS**

- five comparators
- 1 threshold + 2 windows
- four 6-bit DACs (1.6mV step)
- dispersion (adj) < 2.5e$^-$ rms

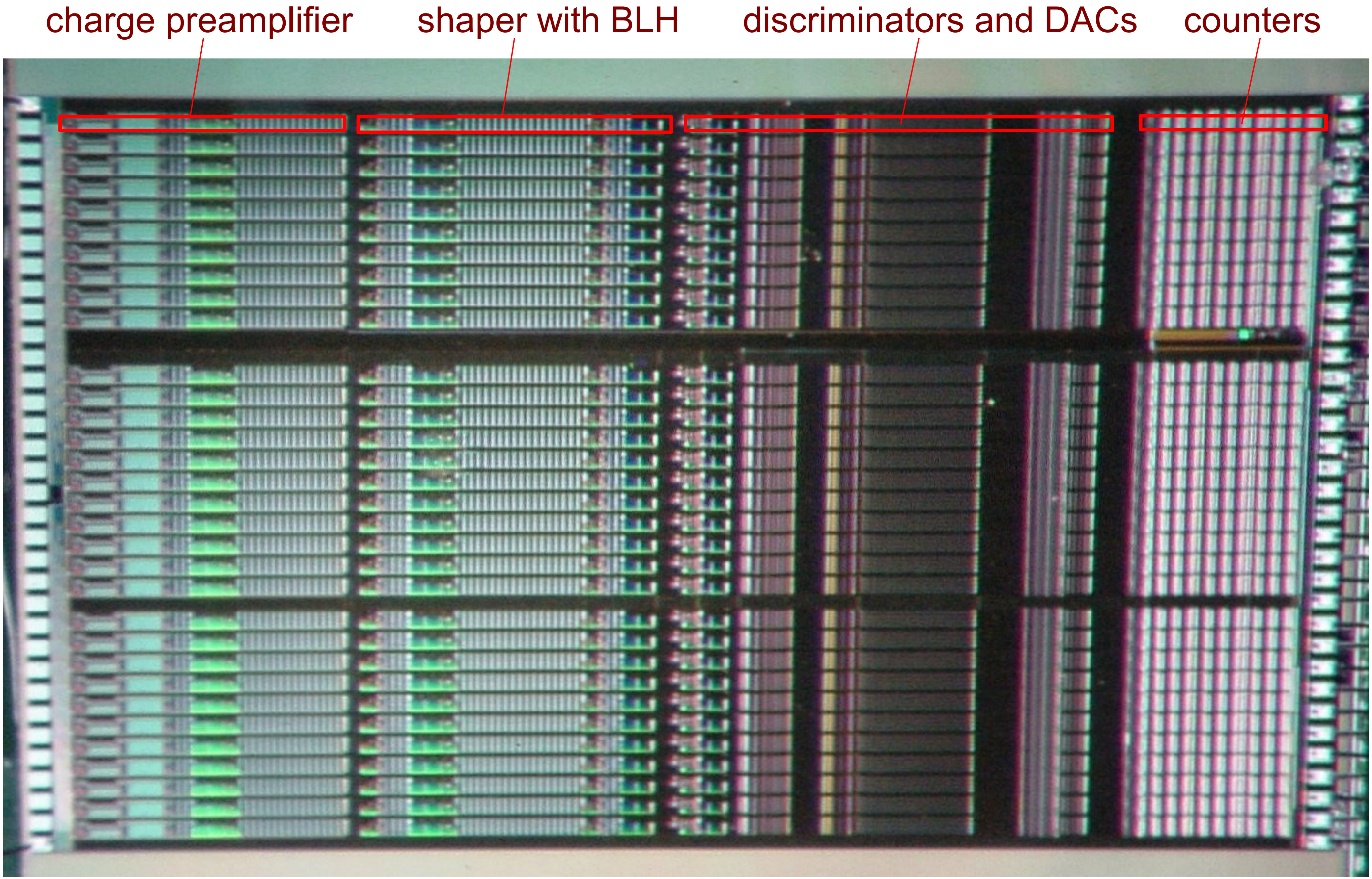
five 10-bit DACs
reference voltages for comparators

**COUNTERS**

- three (one per discriminator)
- 24-bit each

≈ 5 mW

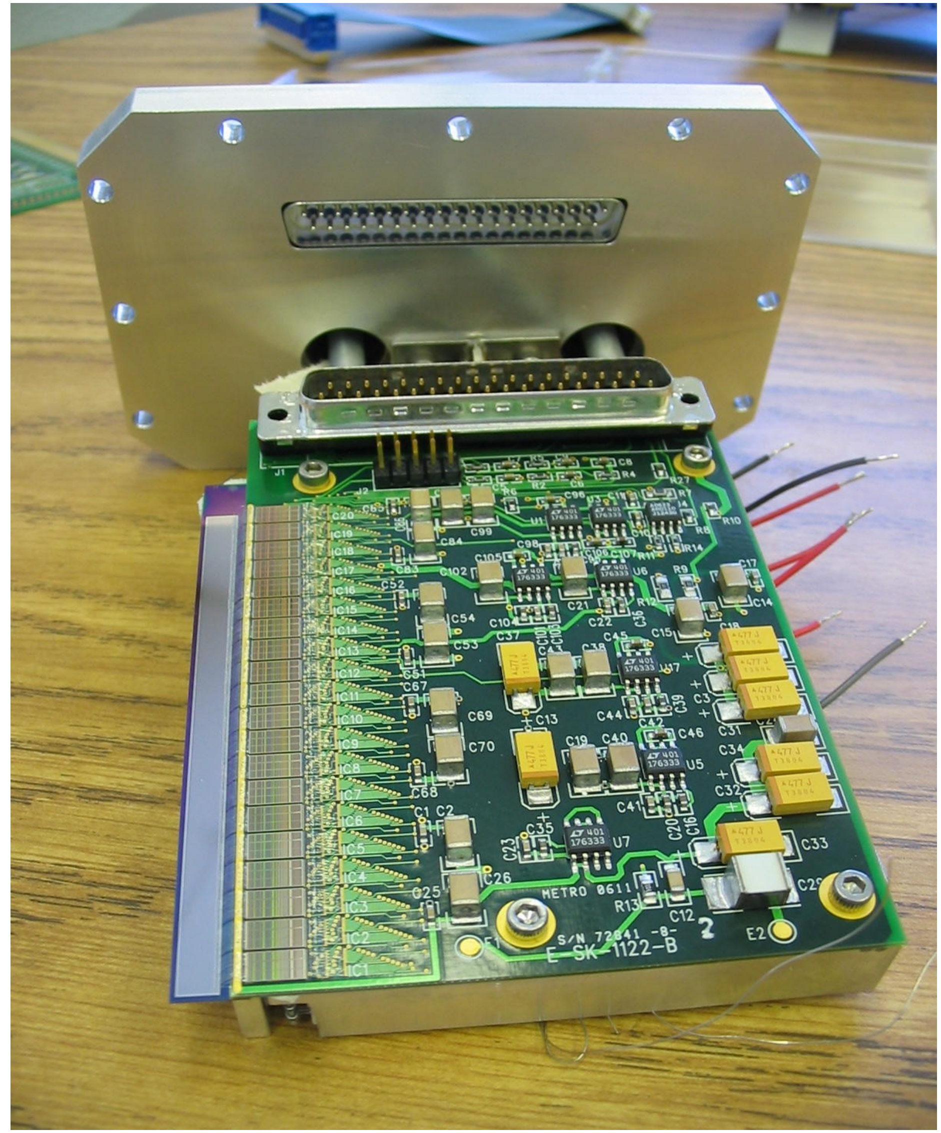
# 'HERMES' ASIC photo

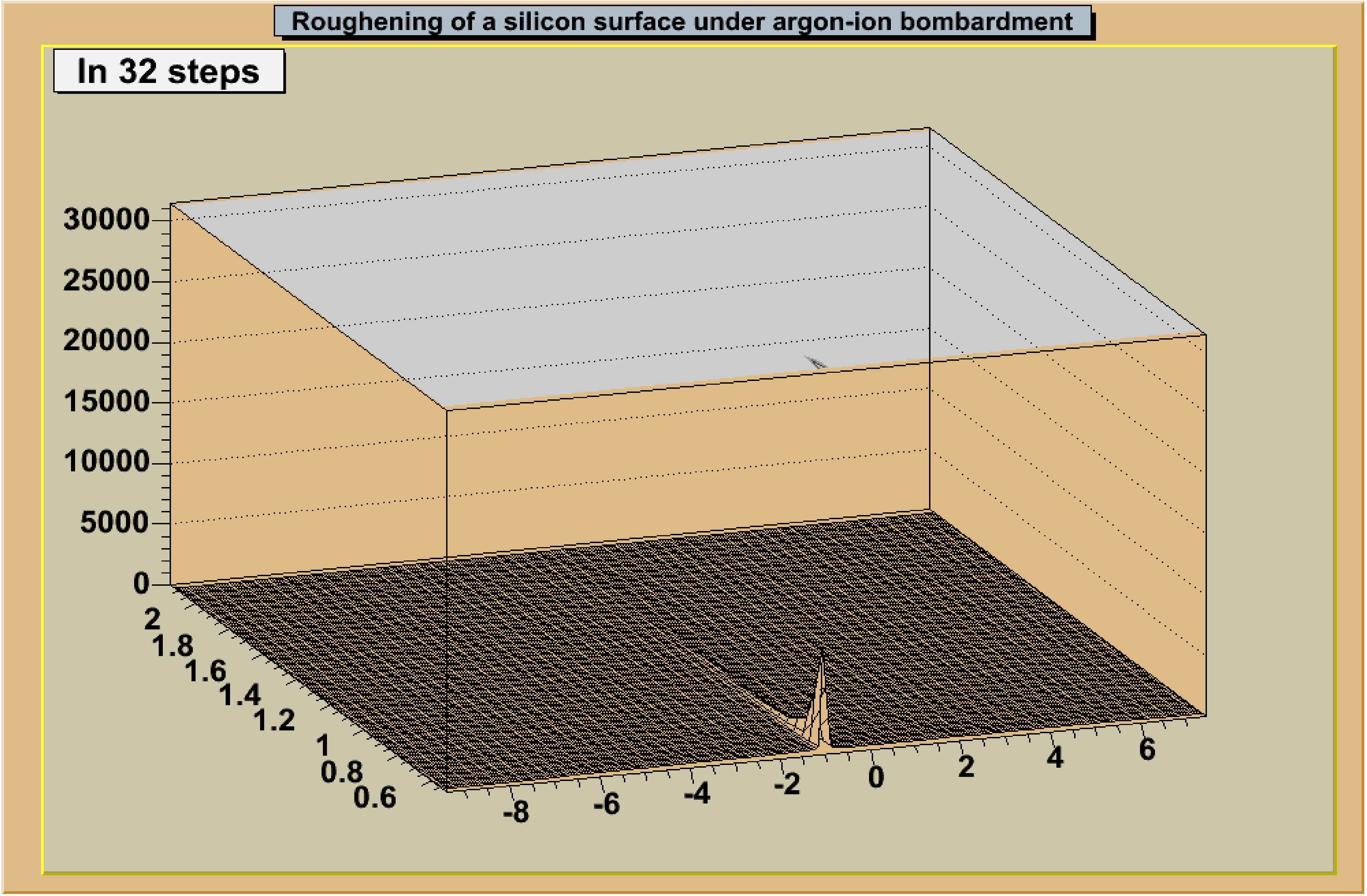



*32 channels, 3.6 × 6.3 mm²*

# Microstrip detector

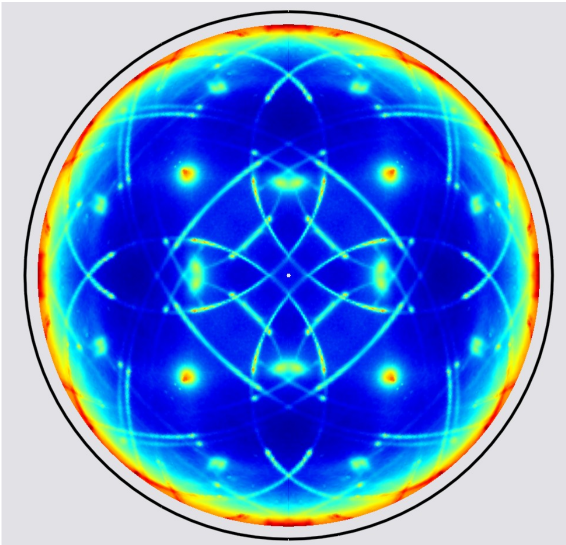
- Diode array (640 strips) at left of picture
- Custom IC's directly to right of strips
- Peltier coolers and water-cooling channels below
- Power regulators and signal buffers to right.
- Diodes cooled to -35C



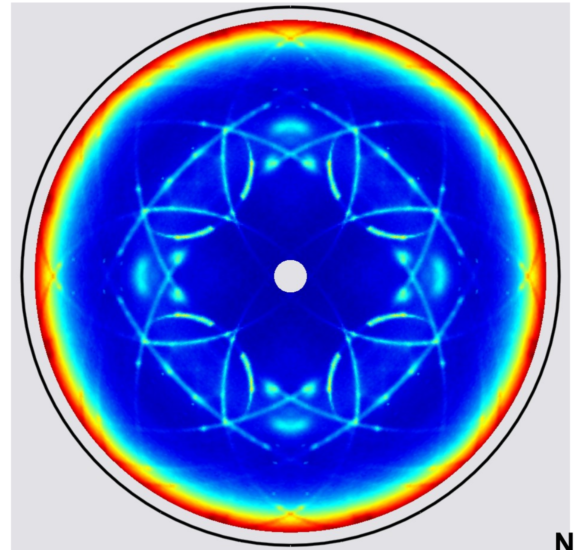

Roughening of a silicon surface under argon-ion bombardment
In 32 steps
30000
25000
20000
15000
10000
5000
0
2
1.8
1.6
1.4
1.2
1
0.8
0.6
-8
-6
-4
-2
0
2
4
6

# First simultaneous pole figures from NSLS linear detector at X20A

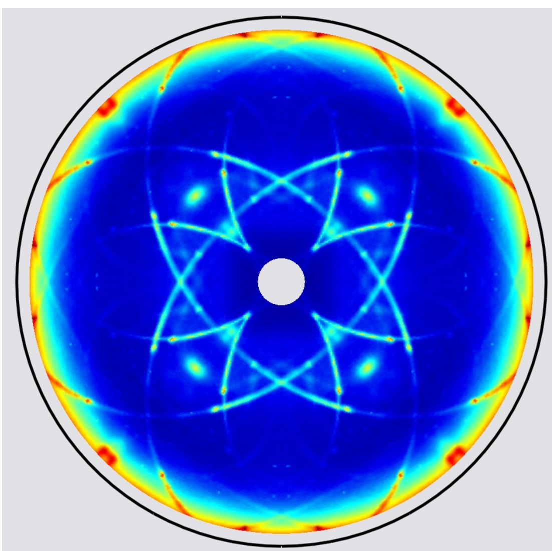
C. Detavernier, K. DeKeyser (U. Gent), D.P. Siddons (NSLS), J. Jordan-Sweet, C. Bohnenkamp



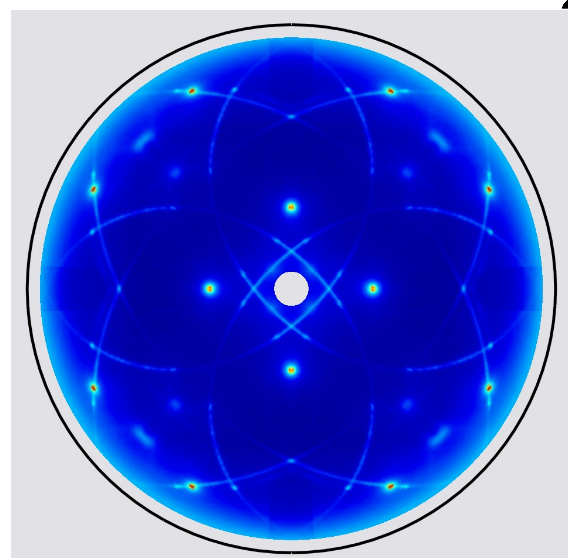
**NiSi 112**
**2θ = 45.82º**



**NiSi 102/111**
**2θ = 36º**



**NiSi 002/011**
**2θ = 31.5º**



**NiSi 013/020**
**2θ = 56.4º**

**(NiSi/Si(001) tiled from 90º phi segments)**

# Maia

- In 2003 I spoke at an SRI conference in San Francisco.
- An Australian, Chris Ryan, approached me to suggest a collaboration to make a novel detector for x-ray microprobe applications, based on our detectors and his software and firmware.
- The result is a paradigm-changing system for elemental mapping, which Paul O'Connor dubbed Maia.

# Energy and time readout

ELSEVIER

Nuclear Instruments and Methods in Physics Research A 484 (2002) 544–556

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

www.elsevier.com/locate/nima

Analog CMOS peak detect and hold circuits. Part 2. The two-phase offset-free and derandomizing configuration☆

Gianluigi De Geronimo*, Paul O'Connor, Anand Kandasamy

- Hermes did not have all analog outputs, and we did not have an easy way to digitize the outputs. This paper was the start of the answer.

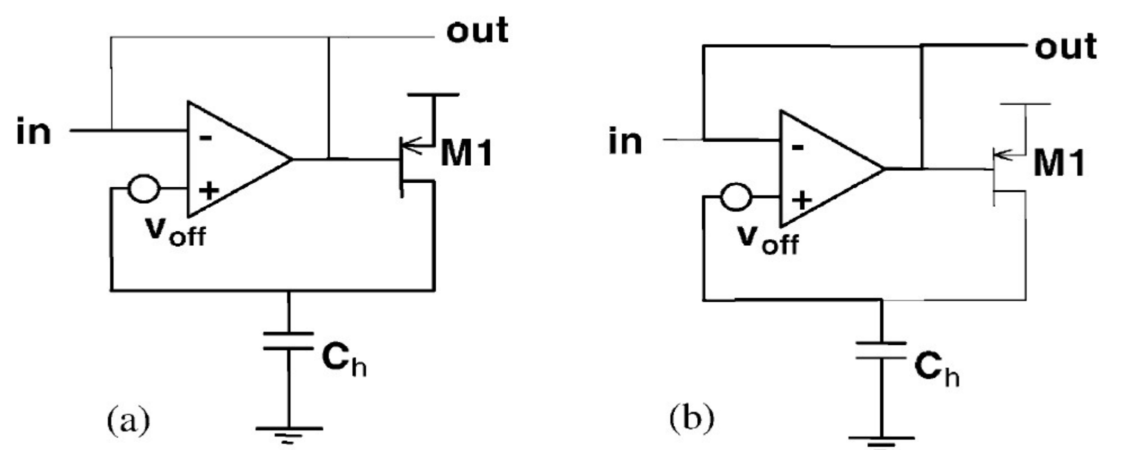



Fig. 2. Simplified schematic of the two-phase peak detector: (a) WRITE phase and (b) READ phase.

# Scepter

2005 IEEE Nuclear Science Symposium Conference Record N16-7

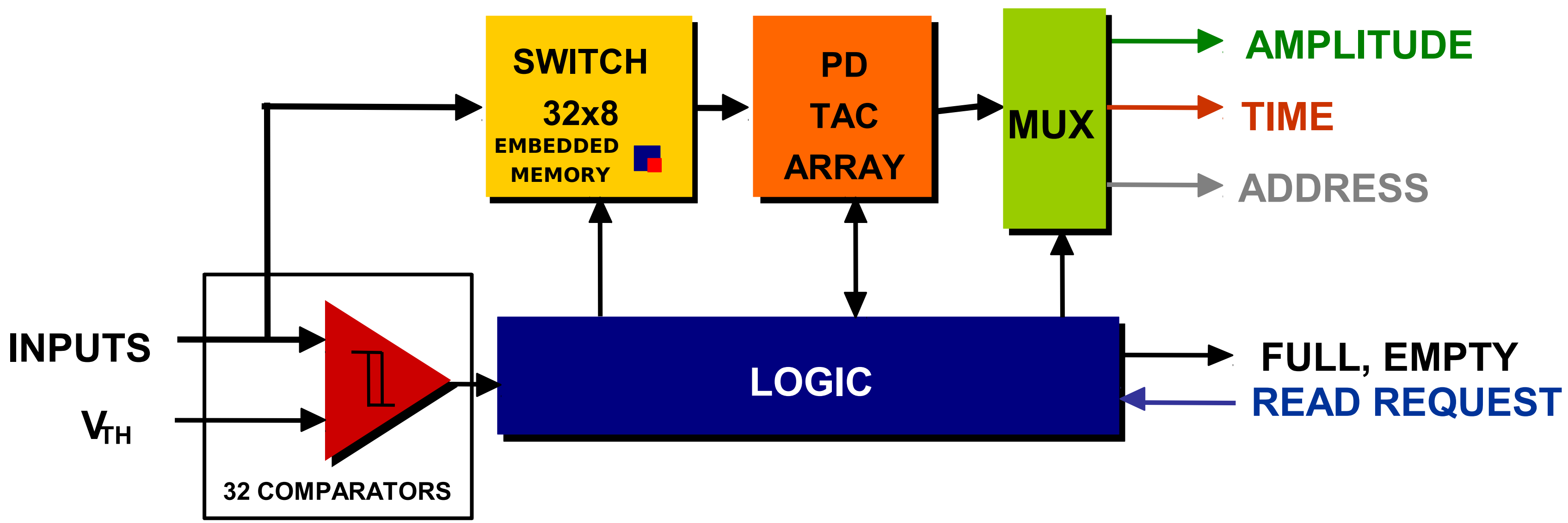
The PDD ASIC: Highly Efficient Energy and Timing Extraction for High-Rate Applications

Angelo Dragone, Gianluigi De Geronimo, Jack Fried, Anand Kandasamy, Paul O'Connor and Emerson Vernon

- Hermes did not provide energy information, only photon counts within a few amplitude windows.
- The microelectronics group designed a circuit which efficiently captured peak amplitudes for 32 inputs using eight peak-detector circuits and an arbitration circuit.
- Hermes was modified to bring out all 32 analog pulses.
- This combination allowed full spectral information from all channels simultaneously.

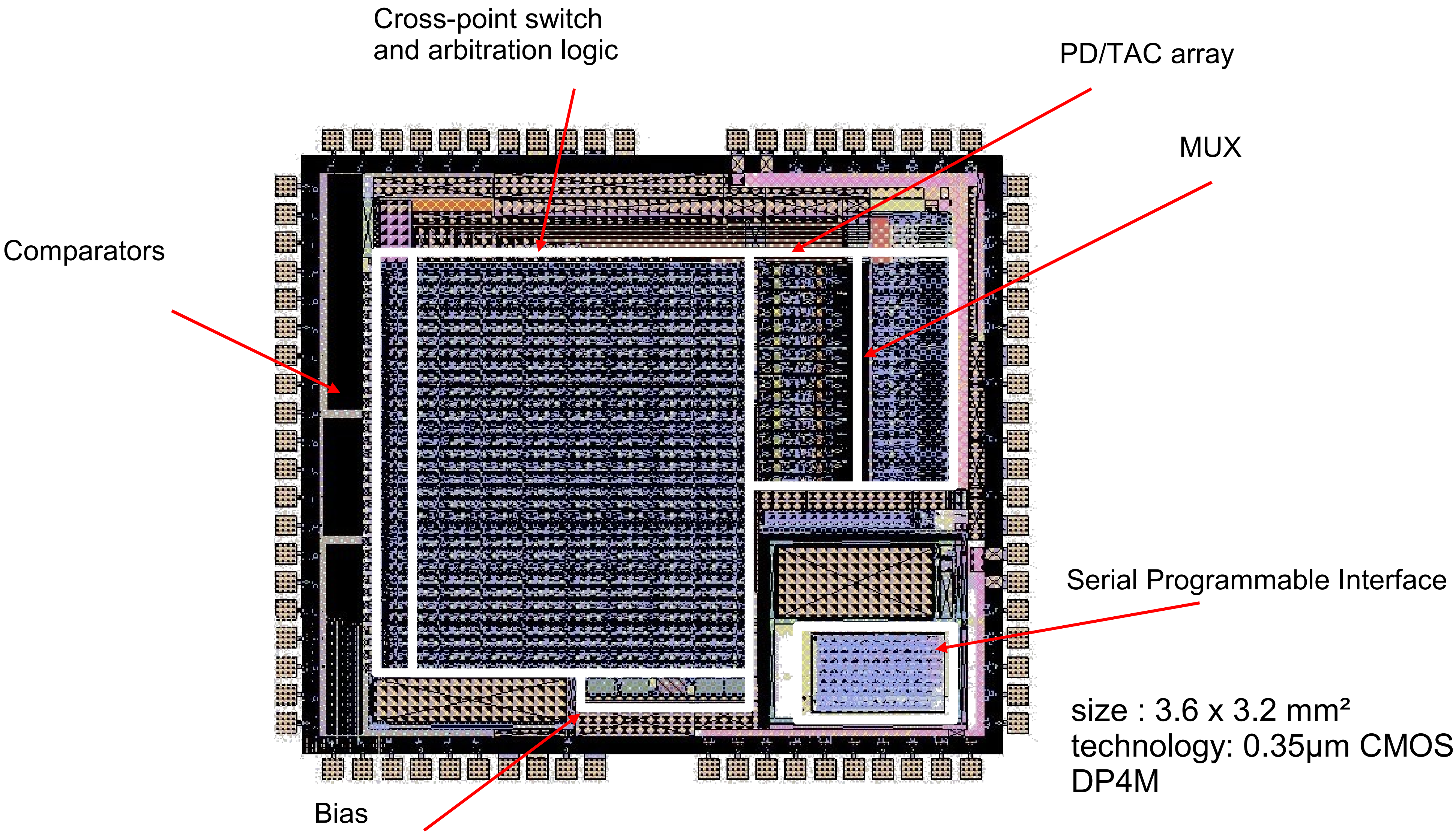
# SCEPTER: The Peak Detector Derandomizer ASIC

(A. Dragone, G. De Geronimo, P. O'Connor)



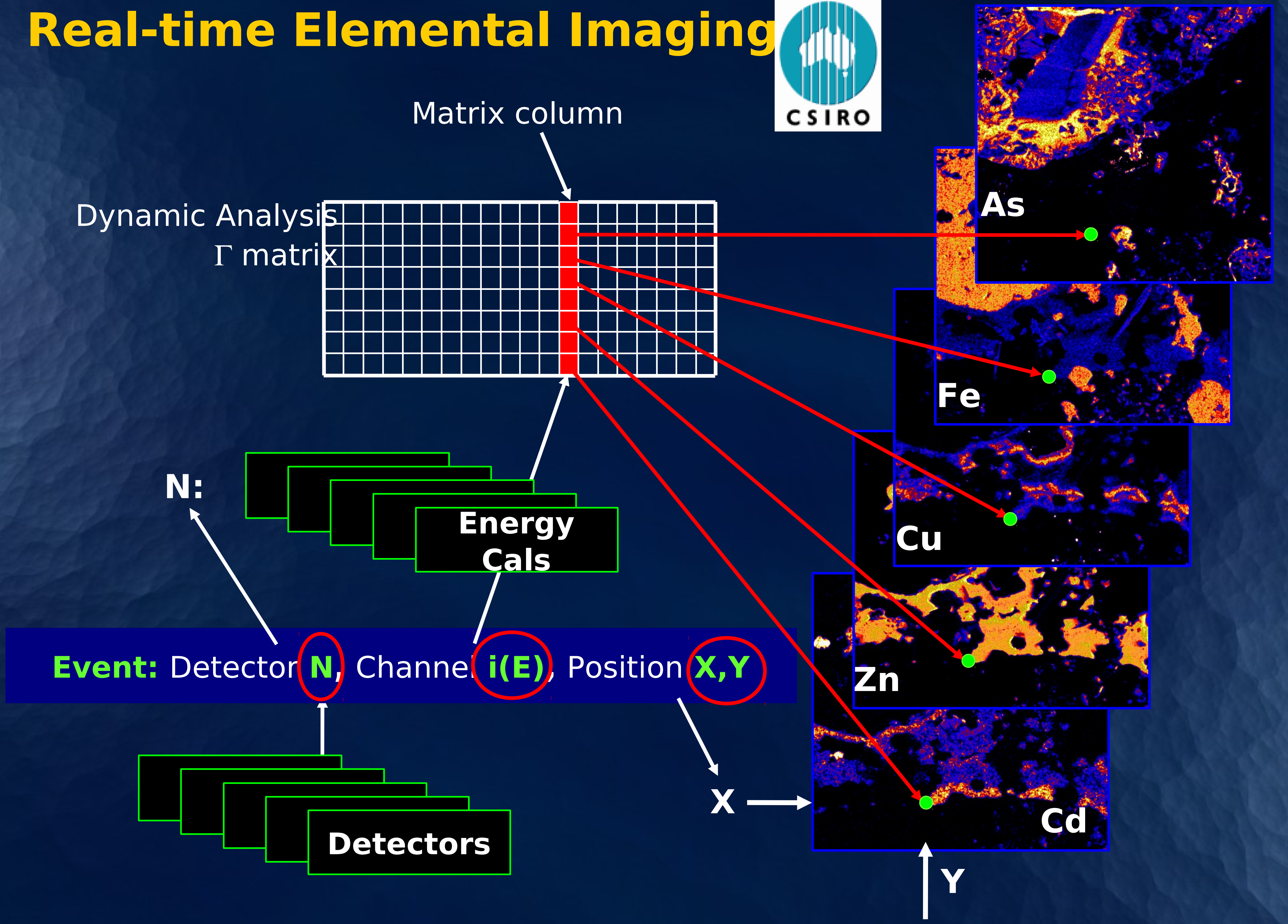

- New architecture for efficient readout of multichannel detectors
  - *Self-triggered and self-sparsifying*
  - *Simultaneous amplitude, time, and address measurement for 32 input channels*
  - *Set of 8 peak detectors act as derandomizing analog memory*
  - *Rate capability improvement over present architectures*
- Based on new 2-phase peak detector combined with Quad-mode TAC
  - *High absolute accuracy (0.2%) and linearity (0.05%), timing accuracy (5 ns)*
  - *Accepts pulses down to 30 ns peaking time, 1.6 MHz rate per channel*
  - *Low power (2 mW per channel)*

# PDD Layout

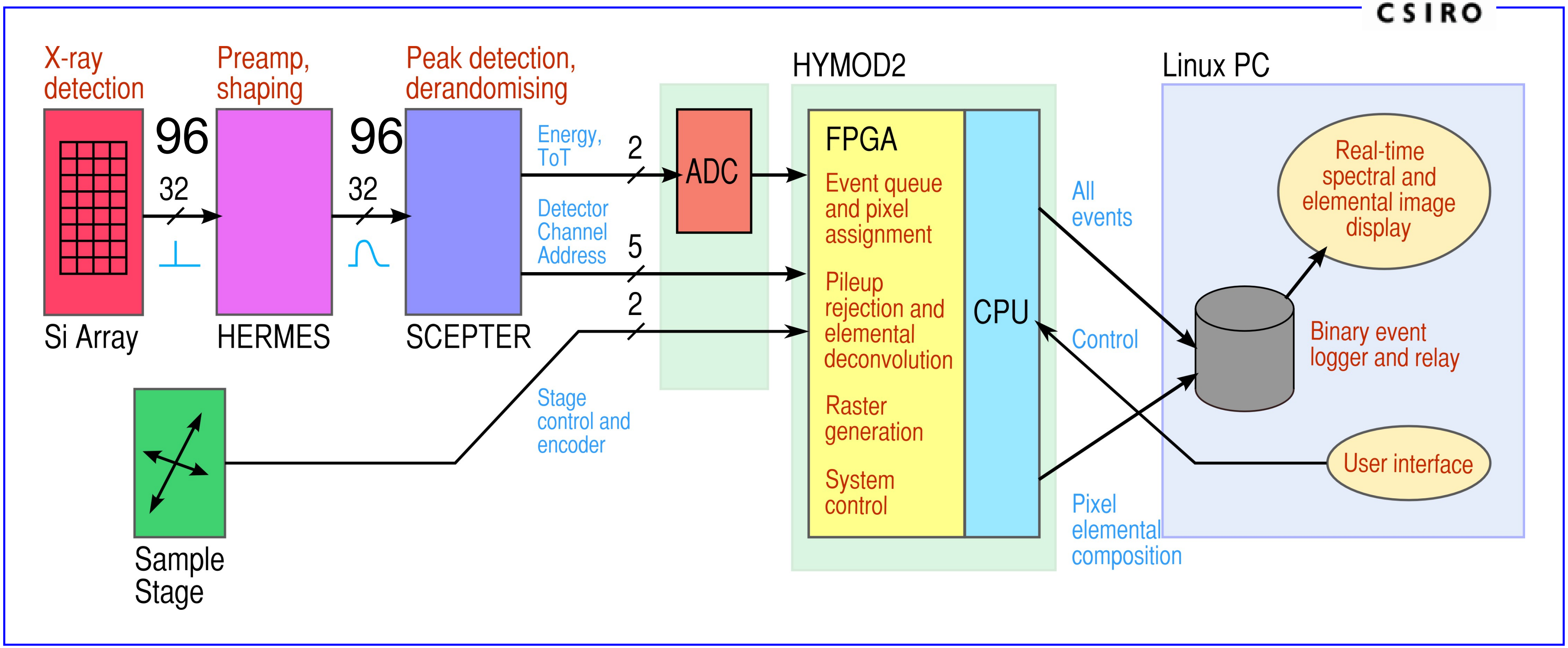



size : 3.6 x 3.2 mm²
technology: 0.35μm CMOS
DP4M

# Real-time Elemental Imaging

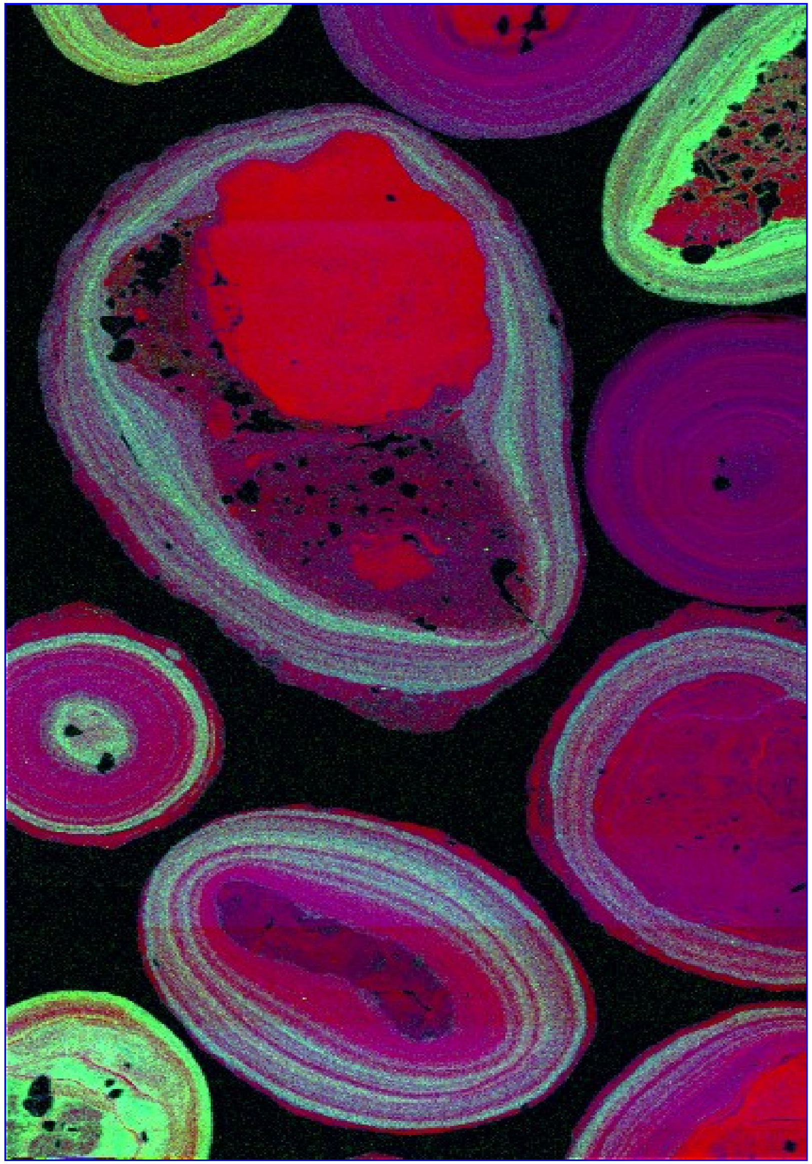


# Demonstration experiment at X27A: Block diagram of test setup




- HYMOD controls stage and reads detector
- Each photon tagged with energy, XY position and pileup status
- Initial coarse scan generates 'average' spectrum which makes DA matrix
- DA technique then presents elemental map as acquisition proceeds.

# Rapid XRF Elemental Mapping (BNL/CSIRO collaboration)

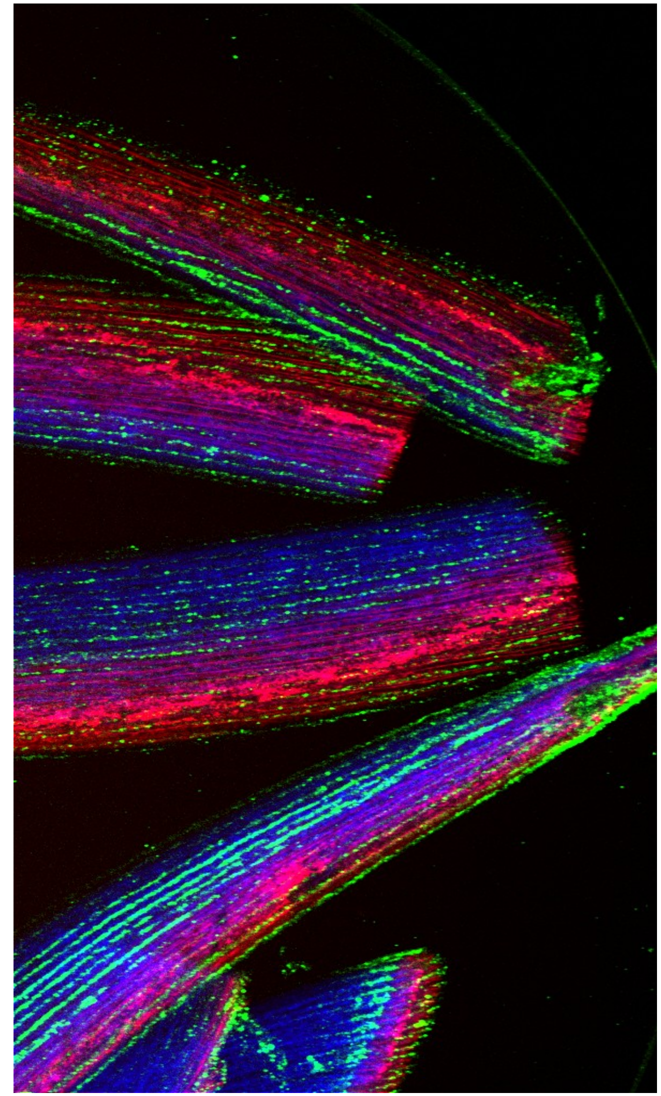


Fe-Y-Cu RGB composite (1500 x 2624 pixel images, 13 x 21 mm$^2$)

1200 x 2267 (9 x 17 mm$^2$)

5.7 hours (7.5 ms dwell)

7.5 x 7.5 μm$^2$ pixels



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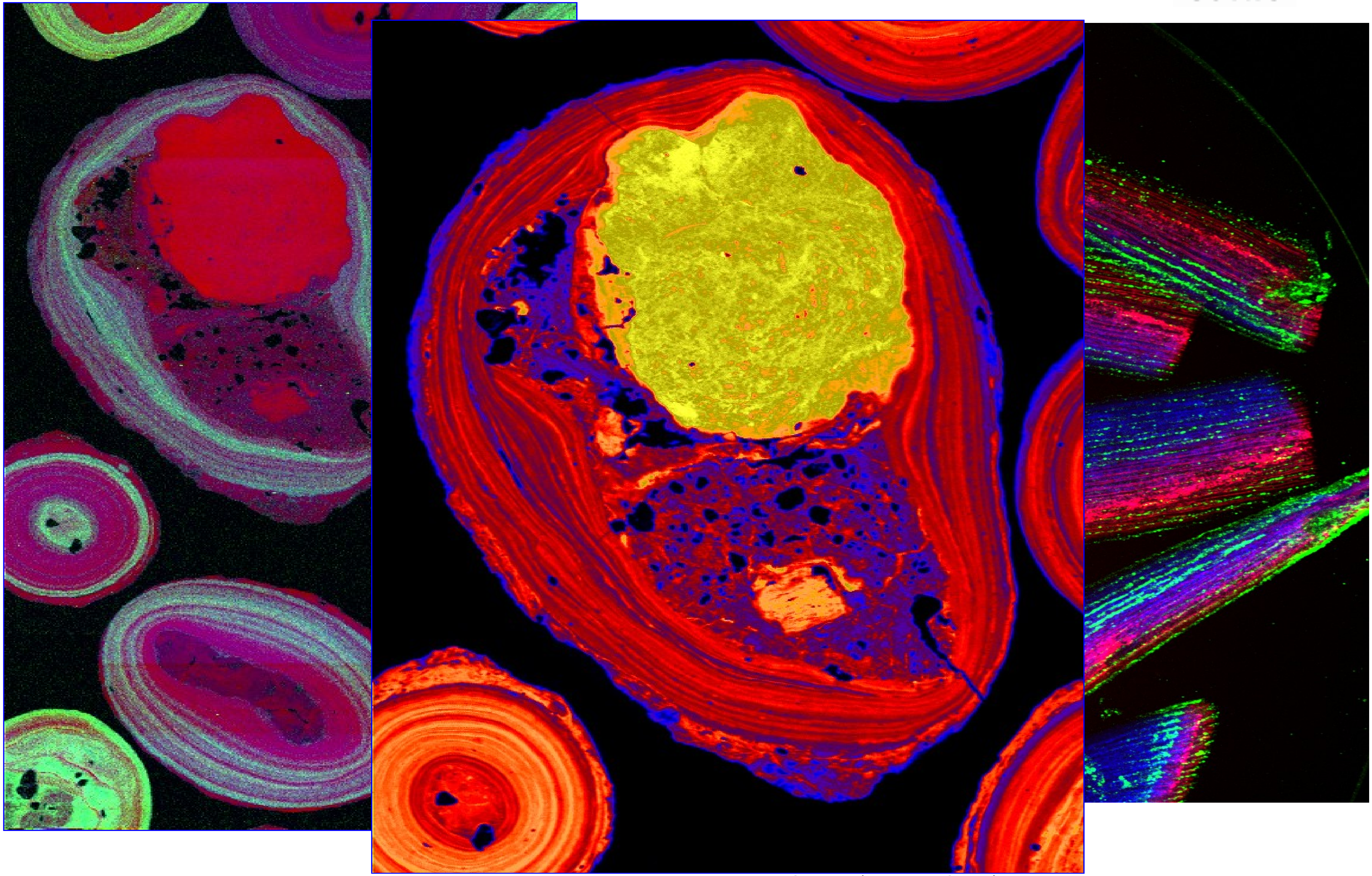

5.7 hours (7.5 ms dwell)

7.5 x 7.5 μm$^2$ pixels

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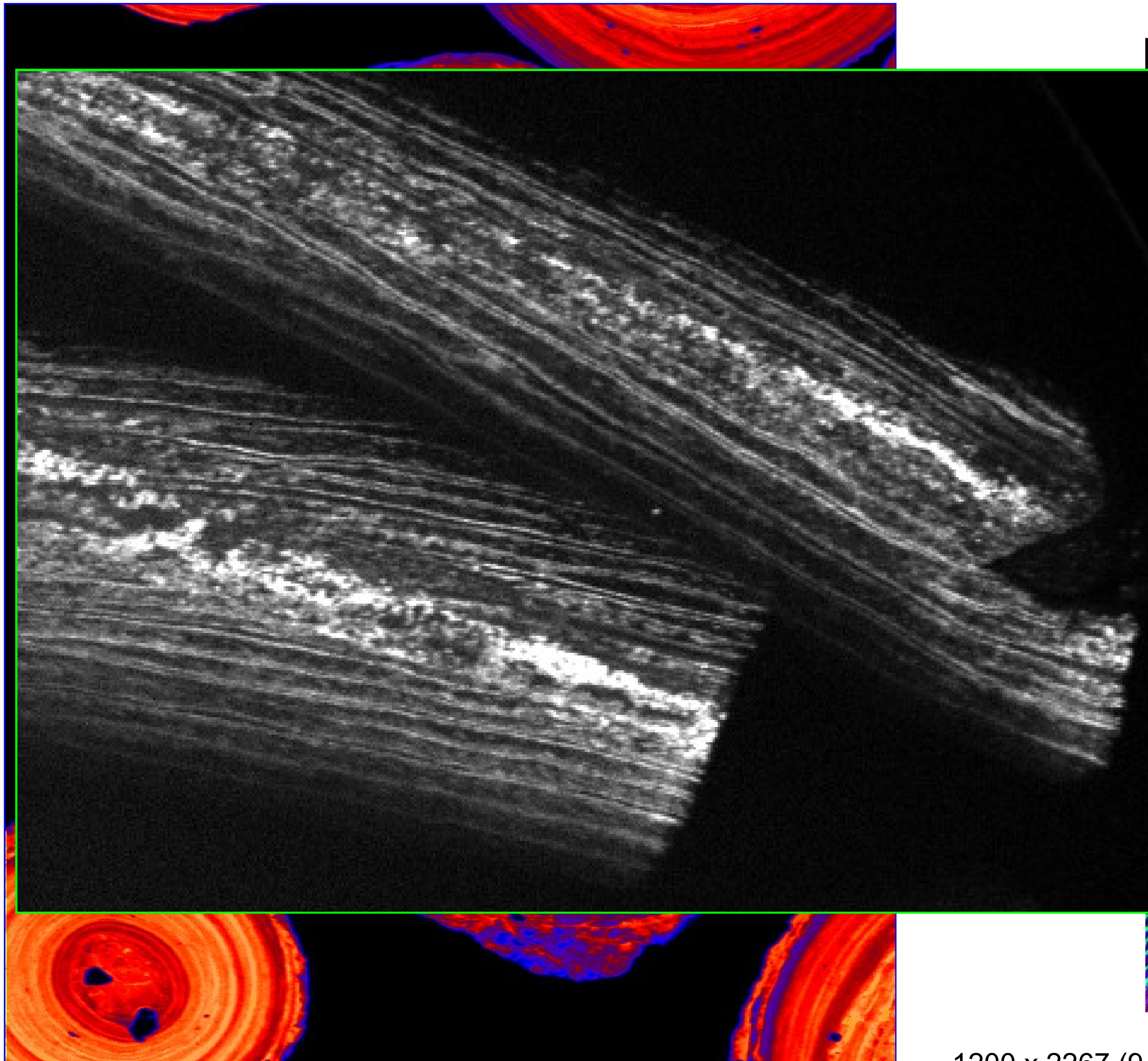
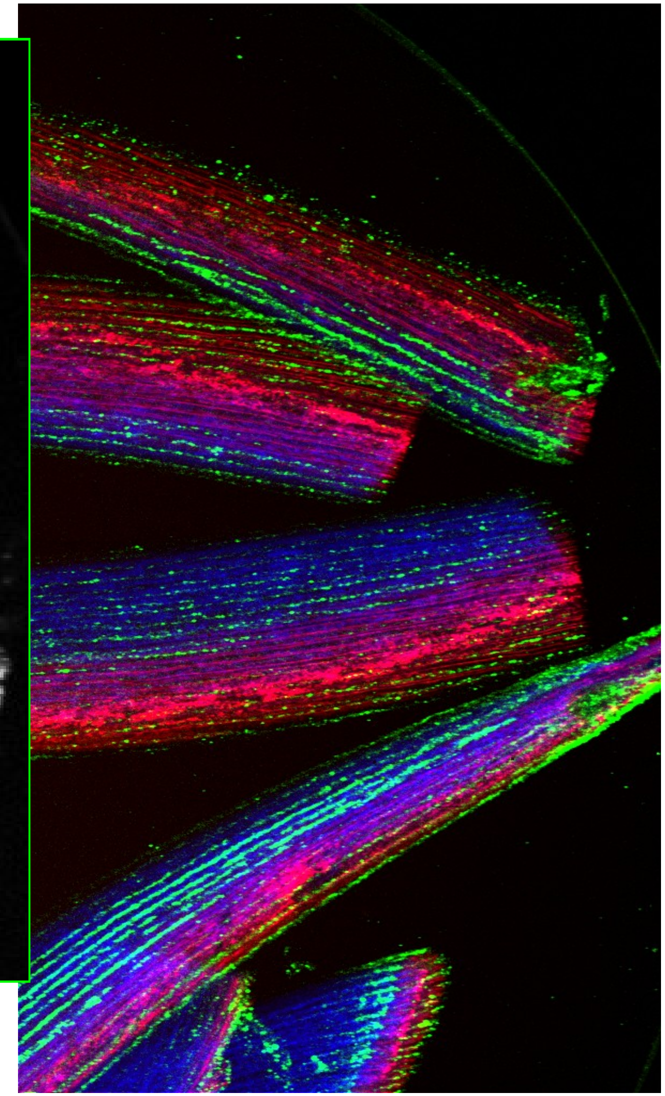




1200 x 2267 (9 x 17 $mm^2$)

5.7 hours (7.5 ms dwell)

7.5 x 7.5 $\mu m^2$ pixels

# The future

**SEMICONDUCTOR DRIFT CHAMBER – AN APPLICATION OF A NOVEL CHARGE TRANSPORT SCHEME**

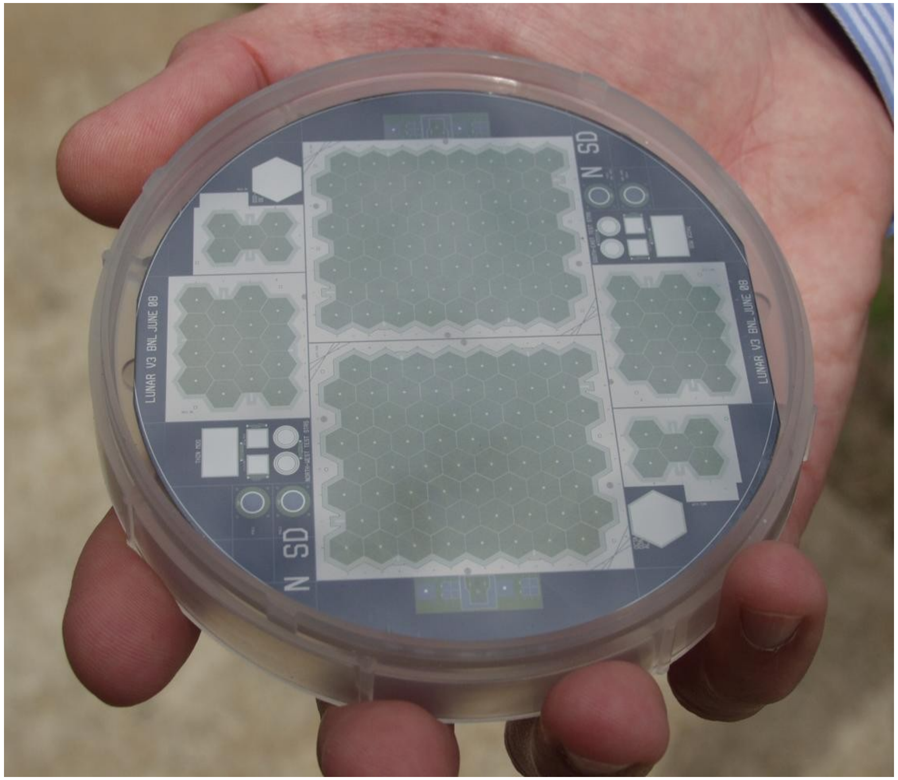
Emilio GATTI [1)] and Pavel REHAK

*Brookhaven National Laboratory, Upton, New York 11973, USA*

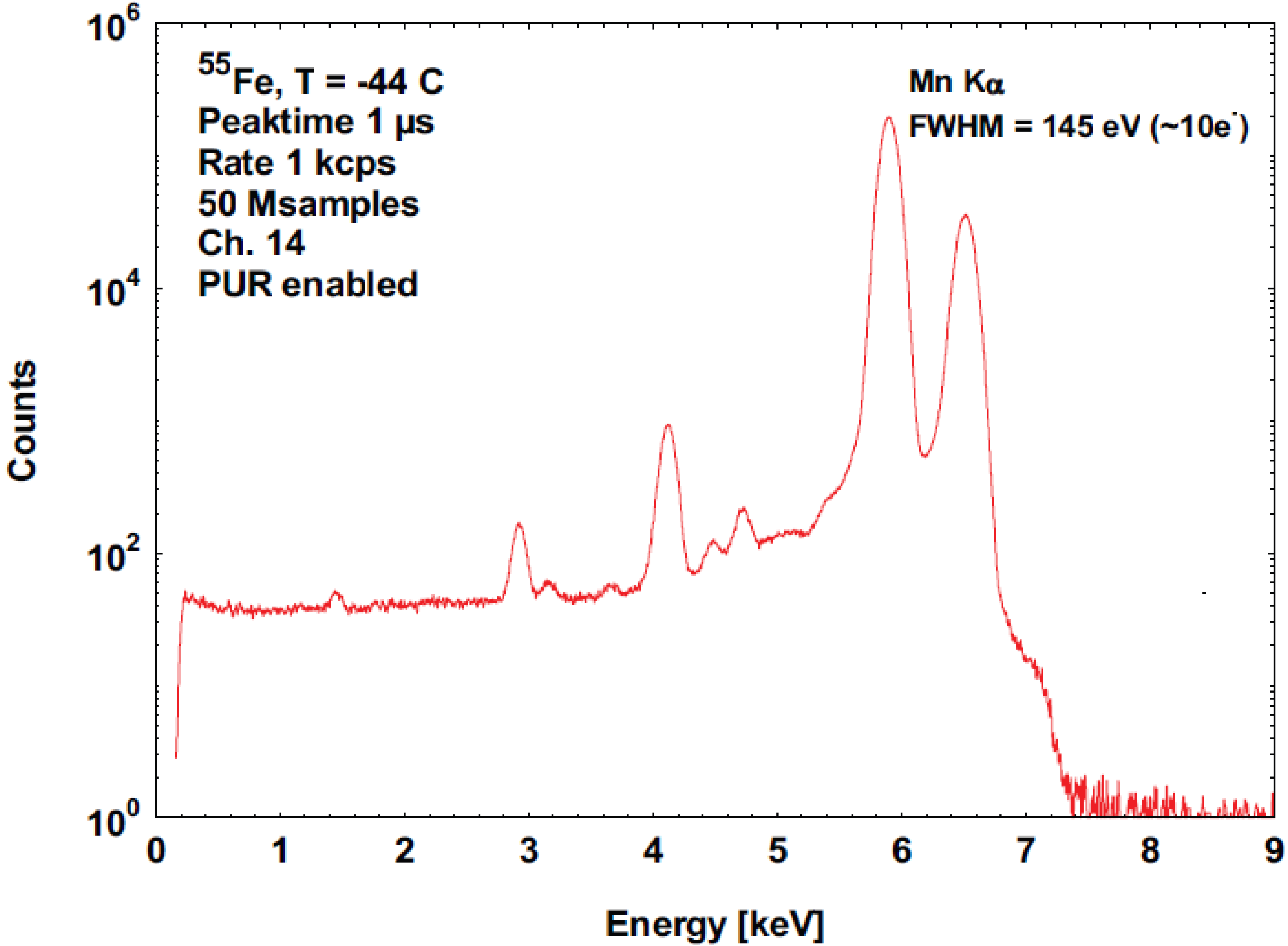
- Invented at BNL in 1984, slow to be adopted by the SR community
- Silicon Drift Detectors (SDDs) have become the spectroscopy detector of choice for energies below 20keV
- Instrumentation has a collaboration with NASA to develop large arrays of SDDs for space missions.
- Some of those arrays are ideal for SR applications.

# Moving forward with spectroscopy

- NSF grant with Trevor Tyson (NJIT) to develop EXAFS and fluorescence holography detectors based on MAIA technology
- Will take MAIA and drift detector technology being developed for NASA and adapt it to EXAFS.
- NASA project will produce a 0.5m^2 array of drift detectors to fly in low-moon orbit, collecting x-ray fluorescence produced by solar wind. We have joined this project by helping with device testing, in exchange for access to detector arrays.
- Arrays of up to 64 SDDs have been successfully fabricated both at BNL and by Ketek.
- Custom ASIC for SR applications under design



# 55Fe spectrum



# Summary

- This brief history of one project illustrates how Veljko has steered the department to keep it ahead of the ever-changing technology by putting in place the right people and the necessary resources over several decades.
- Quite an achievement!